Patent Translations Inc.

111 Livingston Street, Suite 1110
Brooklyn, NY 11201, USA
Fax 1-800-844-5695 (or 212-898-0125)
mail@PatentTranslations.com
http://www.PatentTranslations.com
Tel: 1-800-844-0494 (or 718-210-4775)

CERTIFICATION

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This is to certify that the above-stated document was translated by Martin Cross from Japanese into English, and that it represents an accurate and faithful rendition of the original text to the best of my knowledge and belief.

By:

December 10, 2007

Martin Cross is the president of Patent Translations Inc. and has worked for nineteen years as a Japanese to English translator and translation editor specialized in patent documents.

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(21) **Application No.:**	2000-149480 (P2000-149480)	(71) **Applicant:**	000002082 Suzuki Motor Corporation 300 Takatsuka-cho, Hamamatsu-shi, Shizuoka-ken
(22) **Application Date**	May 22, 2000	(72) **Applicant:**	000006105 Meidensha Corporation 2-1-17, Osaki, Shinagawa-ku, Tokyo
		(72) **Inventort:**	KOMATA, Yoshiaki 300 Takatsuka-cho, Hamamatsu-shi, Shizuoka-ken Suzuki Motor Corporation
		(74) **Agent:**	100062199 Patent attorney, SHIGA, Fujiya (and one more person)

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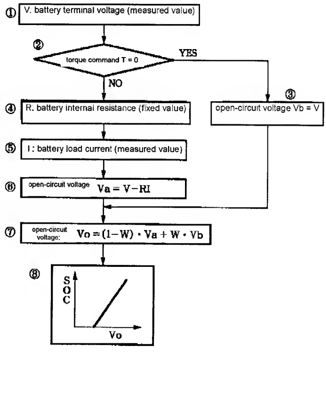
[Title of the Invention] Battery State-of-Charge Estimation Device

(57) **[Abstract]**
[Problem to Be Solved] To correctly estimate battery state of charge (SOC) without errors in the computation of battery open-circuit voltage.
[Means for Solving the Problem] In 1) battery terminal voltage is measured; in 2) a determination is made as to whether or not the battery is under load based on a torque command for the load (motor); in 3) the open circuit voltage when the load is operated [*sic*[1]] is found as Vb=V; in 6) the open circuit voltage Va when the battery load is operated is found as Va=V-RI from the battery internal resistance R, the terminal voltage V and the load current; in 7) the battery open circuit voltage is found as Vo=(1-W) · Va+W · Vb by applying a weighting W to Va and Vb; and in 8) the SOC is estimated by way of calculation based on the Vo. In this SOC estimation, because the open circuit voltage Vo of the battery is calculated by way of a process of computing the battery open circuit voltage Vo, with the open circuit voltage when not under load Vb, which has high voltage-precision, weighted with respect to the estimated open circuit voltage when under load Va, which has insufficient voltage-precision, the Vo estimation precision is increased and thus the SOC estimation precision is improved.

1 *From the context, it appears that this should be "when the load is NOT operated" – trans.*

SOC Computation Flow (R fixed value)



[CLAIMS]

[Claim 1] In a battery state-of-charge estimation device that estimates battery open-circuit voltage based on battery terminal voltage, battery load current and battery internal resistance, and estimates the state-of-charge of a battery based on this estimated battery open-circuit voltage,

the battery state-of-charge estimation device characterized in that said estimated battery open-circuit voltage is calculated by weighting the open-circuit voltage when the battery load is not operated and the estimated open-circuit voltage when the load is operated, resulting from subtracting the battery internal resistance drop from the terminal voltage when the battery load is operated.

[Claim 2] A battery state-of-charge estimation device characterized in that, in claim 1,

a battery state-of-charge/internal resistance characteristic map is provided and said battery internal resistance is estimated by way of computational processing using the battery state-of-charge/internal resistance characteristic map, based on the previous value for the battery state-of-charge.

[Claim 3] A battery state-of-charge estimation device characterized in that, in claim 1,

said battery internal resistance is estimated by way of computational processing based on differing battery terminal voltages and battery load currents in a short period of time, in which it can be assumed that the battery open-circuit voltage does not change.

[Claim 4] A battery state-of-charge estimation device characterized in that, in claim 1 or claim 3, if the battery load is an inverter motor, a map of the total efficiency of the inverter motor, including the motor efficiency and the inverter efficiency, is provided;

and for said battery load current, motor output is found based on the speed of, and a torque command for, the inverter motor, which is the battery load, at the present time, battery output power is found based on the efficiency deduced from this motor output and said inverter motor total efficiency map, and the battery load current is calculated based on this battery output power and the battery terminal voltage.

[Detailed Description of the Invention]

[0001]

[Technical Field of the Invention] This invention relates to a battery state-of-charge estimation device, which estimates the charge remaining in a battery, in a system that drives a motor with a battery as an energy source, such as an electric automobile or a hybrid electric automobile.

[0002]

[Prior Art] In general, the battery state-of-charge (SOC) is closely related to the open-circuit voltage of the battery, and thus the SOC can be estimated from the open-circuit voltage.

[0003] Under load, the open-circuit voltage of the battery cannot be estimated directly, but it can be calculated from the battery terminal voltage, the battery internal resistance (fixed value) and the battery load current (the discharge current or the charge current), and the SOC can be estimated from this value. The calculation flow for this SOC estimation is shown in FIG. 5.

[0004] One example of a device for estimating SOC by estimating open-circuit voltage based on estimated data for voltage and current when current is flowing is shown in FIG. 6. This device: detects the load current of a battery PB; estimates the battery terminal voltage Vj' by way of a first calculation circuit 14 based on A/D converted measured current data Ij; detects the battery voltage and calculates the difference ej between the A/D converted measured terminal voltage data Vj and the aforementioned estimated terminal voltage Vj' with a comparator circuit 15; repeatedly changes a function argument in a first relational expression and performs a computation with the first computation circuit 14, while feeding back the difference ej, so that, based on the difference ej, the first calculation circuit 14 brings the estimated terminal voltage Vj' closer to the measured terminal voltage until ej = 0; and outputs the constant Cj as the estimated open-circuit voltage, so as to calculate the SOC based on the estimated open-circuit voltage with the second calculation circuit 21. (JP-05-142314-A)

[0005]

[Problems to Be Solved by the Invention] Here, because the battery internal resistance R progressively changes in conjunction with the SOC value, it is difficult to accurately estimate the SOC. Furthermore, in order to estimate the load current from the battery (discharge current or charge current), it is necessary to mount a current detection device such as a Hall CT, which increases cost.

[0006] The present invention is directed at solving the problems described above, and an object thereof is to provide a battery state-of-charge estimation device capable of accurately estimating SOC from open-circuit voltage, wherein precision is improved by finding the battery internal resistance based on the previous SOC value and weighting the estimated open-circuit voltages when the load is operating and when the load is not operating.

[0007]

[Means for Solving the Problems] A battery state-of-charge estimation device that estimates battery open-circuit voltage based on battery terminal voltage, battery load current and battery internal resistance, and estimates the state-of-charge of a battery based on this estimated battery open-circuit voltage, is characterized in that the estimated battery open-circuit voltage is calculated by weighting the open-circuit voltage when the battery load is not operated and the estimated open-circuit voltage when the battery load is operated, resulting from subtracting the battery internal resistance drop from the terminal voltage when the battery load is operated.

[0008] The battery internal resistance may be estimated by providing a battery state-of-charge/internal resistance characteristic map and performing computational processing using this characteristic map, based on the previous value for the battery state-of-charge; or this may be estimated by way of computational processing using battery terminal voltages and battery load currents before and after a short period of time, in which it can be assumed that the battery open-circuit voltage does not change.

[0009] Furthermore, if the battery load is an inverter motor, a map of the total efficiency of the inverter motor, including the motor efficiency and the inverter efficiency, may be provided; motor output may be found based on the speed of, and a torque command for, the inverter motor, which is the battery load, at the present time; the battery output power may be found based on the efficiency deduced from this motor output and the inverter motor total efficiency map; and the battery load current may be estimated by calculation based on this battery output power and the battery terminal voltage.

[0010]

[Modes of Embodiment of the Invention] Mode of Embodiment 1

When an electric automobile or a hybrid electric automobile is running normally, the motor torque command is often set to zero. Because the battery current is zero when the torque command is zero, the battery open-circuit voltage is equal to the terminal voltage, so the battery state-of-charge (SOC) can be accurately estimated.

[0011] As shown in FIG. 1, Mode of Embodiment 1 is such that the SOC is estimated by adding a condition in which the torque command value is zero to the conventional SOC estimation calculation flow shown in FIG. 5, as well as performing weighting. The SOC estimation device is constituted by a computation unit comprising: voltage and current detectors that detect the battery terminal voltage and the battery load current; A/D converters that convert the detected voltage and current signals to digital signals; and a CPU that estimates the SOC using this voltage and current data and the like (not shown in the drawing).

[0012] Referring to FIG. 1, a description will be given of the computational processing procedure for estimating SOC with the computation unit of the SOC estimation device described above.

[0013] First, in step 1) the CPU measures the battery terminal voltage V via the A/D converter and, in 2) determines whether or not the torque command T for the motor that is driven by the battery is zero. If the result of the determination is YES ($T = 0$), in 3) the open-circuit voltage Vb is replaced by the battery terminal voltage V. If NO ($T \neq 0$), in 4) and 5) the battery internal resistance R (fixed value) and the battery load current I are obtained, and in 6) the open-circuit voltage is calculated as $Va = V - RI$.

[0014] In 7) Va and Vb are weighted so as to calculate the open-circuit voltage as $Vo = (1-W) \cdot Va + W \cdot Vb$. By calculating with a weighting W, [the system] can be set either so as to give consideration to the open-circuit voltage Va when the load is operating, or so as to give consideration to the open-circuit voltage Vb when the load is not operating. (When $W = 0$, $Vo = Va$; and when $W = 1$, $Vo = Vb$). Then, in 8) SOC is estimated by calculating the SOC based on the open-circuit voltage Vo.

[0015] According to the Mode of Embodiment 1 described above, a condition is added to the conventional SOC estimation method in FIG. 5, for cases where the torque command T is zero, and the SOC is estimated by weighting the open-circuit voltage when under load and when not under load, so as to improve the precision of the SOC estimation.

[0016] Mode of Embodiment 2

It is known that the battery internal resistance R is a function of the battery state-of-charge (SOC) when discharging and when charging.

[0017] As shown in FIG. 2, Mode of Embodiment 2 is such that the SOC is estimated in the same manner as in FIG. 1, but the battery internal resistance R (fixed value) in 4), which is used in the calculation of the open-circuit voltage Va in 6) in FIG. 1, is replaced with an estimated value.

[0018] The computational processing procedure for the estimation of battery internal resistance R in 4) in FIG. 2 is described in FIG. 3. Maps A and B of internal resistance R with respect to SOC when charging and when discharging, respectively, are prepared in advance, and when the result of the determination of whether or not the torque command is zero in 2) in FIG. 2 is NO, a determination is made as to whether or not the torque command T is greater than zero in step 41. If the result of this determination is YES (when discharging), in 42, the battery internal resistance R is estimated from the previously estimated SOC value, by way of the map A; and if this is NO (when charging), in 43, the battery internal resistance R is estimated from the previously estimated SOC value by way of the map B.

[0019] According to Mode of Embodiment 2, because the open-circuit voltage Va is calculated by estimating the battery internal resistance R, the SOC estimation precision is better than in the case of FIG. 1 as described above.

[0020] Mode of Embodiment 3

In Mode of Embodiment 3, SOC is estimated according to the SOC estimation calculation flow in FIG. 2, in the same manner as Mode of Embodiment 2, but battery internal resistance R in 4) is estimated by way of a calculation that uses the battery terminal voltage V and the load current I.

[0021] The battery internal resistance estimation method according to Mode of Embodiment 3 will be described. The relationship between battery open-circuit voltage Vo, terminal voltage V and internal resistance R is shown by Equation (1).

[0022] $Vo = V - R \cdot I$ ...(1)

Here, if a short period of time is assumed, the battery open-circuit voltage Vo does not change and thus SOC likewise does not change, and therefore if the voltage and current data are detected under two differing load conditions during this short period of time, Equation (4) is arrived at from Equations (2) and (3), and the battery internal resistance R can be estimated from Equation (5).

[0023]

$$Vo = V1 - R \cdot I1 \quad ...(2)$$

$$Vo = V2 - R \cdot I2 \quad ...(3)$$

From (2) - (3), $V1 - V2 = R \cdot (I1 - I2)$ ...(4)

Accordingly, the estimated internal resistance value R is $R = (V1 - V2) / (I1 - I2)$ ...(5)

Here, V1 and V2 are the measured values for the voltage between the battery terminals, and I1 and I2 are the measured values for the battery load current.

According to Mode of Embodiment 3, estimation of the battery internal resistance R, in 4) in the calculation flow in FIG. 2, can easily be performed by way of Equation (5).

[0024] Mode of Embodiment 4

In 5) in the SOC estimation computation flow in FIG. 1, the battery load current I (measured value) is detected with a Hall CT or the like. Mode of Embodiment 4 is such that, if the load is an inverter motor, instead of measuring the load current I in 5) in FIG. 1, the load current I is estimated by way of a computation using voltage VDC (= battery voltage V) (measured value), motor speed ω (measured value) and a torque command T.

[0025] The computational processing procedure for estimation of the load current I is described in FIG. 4. A map C of the total efficiency η of the inverter motor, which includes the motor efficiency and the inverter efficiency in relation to the torque command T and the motor speed ω, is prepared in advance.

[0026] If the result of determining whether or not the torque command T is zero in 2) in FIG. 1 is NO, in 51, the DC voltage VDC (measured value), the motor speed ω (measured value) and the torque command T are

obtained; in 52, the total efficiency η is found from the motor speed ω and the torque command at the present time, using the inverter motor total efficiency map C; in 53, battery output is found as P = ωT/η from the motor output ωT and the total efficiency η, which was deduced from the motor speed ω and the torque command at the present time; and in 54, battery load current is calculated as I = P/VDC from the battery output P and the DC voltage VDC.

[0027] In electric automobiles and hybrid electric automobiles and the like, the motor speed is measured. In Mode of Embodiment 4, this motor speed is used to estimate the battery load current, and therefore battery load current detectors such as Hall CTs are not necessary, which is cost effective. Note that this load current calculation method can also be applied to 5) in FIG. 2.

[0028] Mode of Embodiment 5

Mode of Embodiment 5 is such that, in the device of Mode of Embodiment 3, the battery load current I (measured value) in 5) in the calculation flow in FIG. 2 is not measured, and SOC estimation is performed by estimating the battery load current in the same manner as Mode of Embodiment 4.

[0029] In other words, in the computational flow in FIG. 2, the battery internal resistance R (measured value) in 4) is estimated by way of Equation (5) as described above and [for[2]] battery load current I (measured value) in 5), as shown in FIG. 4, the total efficiency η of the inverter motor is found from the inverter motor total efficiency map C, which includes the motor efficiency and the inverter efficiency in relation to the torque command T and the motor speed ω; the battery load voltage is estimated as I = P/VDC from the battery output P and the DC voltage V (measured value); the open-circuit voltage is found in 7) as Vo = (1 - W) · Va + W · Vb from the battery terminal voltage (measured value), the estimated battery internal voltage R and the battery load current; and in 8), the SOC is estimated by calculating based on the open-circuit voltage Vo.

[0030] According to Mode of Embodiment 5 as described above, because the battery load current is estimated, there is no need for a Hall CT or the like, which is more cost effective than Mode of Embodiment 3.

[0031]

[Effects of the Invention] Because this invention has the constitution described above, it provides the effects recited below.

(1) Because calculation processing is performed with weighting of the open-circuit voltage when the load is not operating, in which the voltage precision is high, with respect to the estimated open-circuit voltage of the battery when the load is operating, in which voltage precision is insufficient, the battery open-circuit voltage computation accuracy is increased, and thus SOC estimation precision is improved.

(2) Because battery internal resistance during discharge and during charge is a function of SOC, if the battery internal resistance is estimated based on the previous SOC value, using a SOC/battery internal resistance characteristic map, SOC estimation precision is improved.

(3) If battery internal resistance is estimated from different battery terminal voltages and currents in a short period of time during which it can be assumed that the battery open-circuit voltage does not change, it is possible to estimate battery internal resistance with a relatively simple computation.

(4) If the battery load current is estimated, there is no need for battery current detectors such as Hall CTs, which is cost effective.

[BRIEF DESCRIPTION OF THE DRAWINGS]

[FIG. 1] is a SOC computation flowchart for an SOC estimation device according to Mode of Embodiment 1 of this invention.

[FIG. 2] is a SOC computation flowchart for an SOC estimation device according to Mode of Embodiment 2 of this invention.

[FIG. 3] is a battery internal resistance estimation flowchart for the same device.

[FIG. 4] is a battery load current computation flowchart for an SOC estimation device according to Mode of Embodiment 4 of this invention.

[FIG. 5] is a SOC computation flowchart for an SOC estimation device according to a conventional example.

[FIG. 6] is a block diagram showing an SOC estimation device according to a conventional example.

FIG. 3

Internal Battery Resistance Estimation Flow

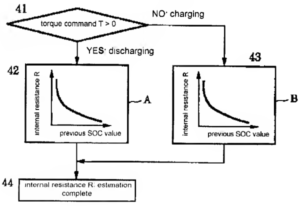
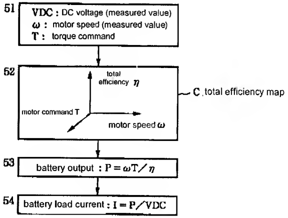


FIG. 4

Battery Load Current Computation Flow



[2] *The original Japanese is grammatically incorrect. The translation represents the most likely intended meaning of the sentence. However, it is also possible that one or more intended words are missing from the original Japanese. – trans*

FIG. 1

SOC Computation Flow (R fixed value)

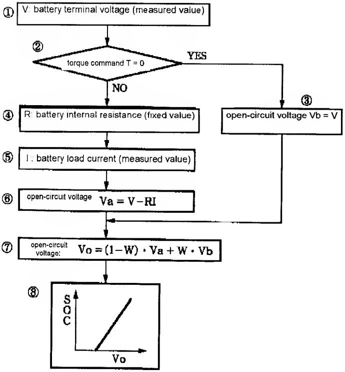
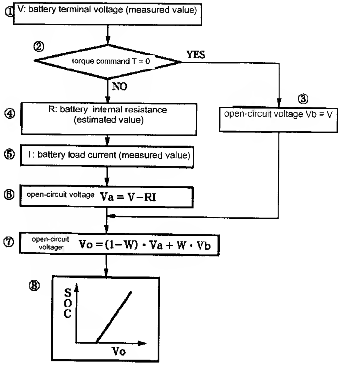


FIG. 2

SOC Computation Flow (R estimated value)



T: motor control torque command value

FIG. 5

SOC Computation Flow (conventional example)

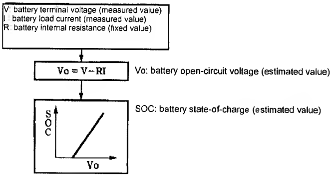
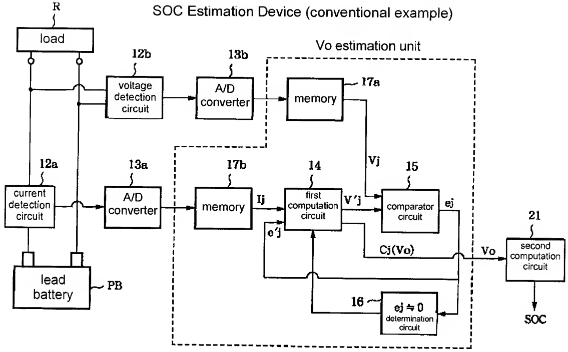


FIG. 6



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(72) Inventor: SUGIYAMA, Hideo
300 Takatsuka-sho
Hamamatsu-shi, Shizuoka-ken
Suzuki Motor Corporation

(72) Inventor: NAKANO, Yoshinori
2-1-17, Osaki, Shinagawa-ku, Tokyo
Meidensha Corporation

(72) Inventor: ASHIKAGA, Tadashi
2-1-17, Osaki, Shinagawa-ku, Tokyo
Meidensha Corporation

(72) Inventor: NOSAKA, Katsunori
2-1-17, Osaki, Shinagawa-ku, Tokyo
Meidensha Corporation

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